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# ICE/ISEE Plasma Wave Data Analysis

Principal Investigator: E. W. Greenstadt
Project Manager: S. L. Moses

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TRW Space and Technology Group
Applied Technology Division
Bldg. R1, Room 1170
One Space Park
Redondo Beach, California 90278

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## INTRODUCTION

*History*. The ISEE-3 spacecraft spent four years hovering around the Earth's sunward Lagrangian point before being brought into eccentric orbits around the Earth to be redirected to comet Giacobini-Zinner (G-Z) and renamed ICE, in 1983, and thence to a cruising orbit around the sun in the solar wind, where it continues still. TRW's plasma wave (pw) detector has opereted nominally throughut the life of the spacecraft, delivering to its investigators unique data: 1. in the solar wind in a position fixed upstream from Earth; 2. around Earth through magnetosphere, magnetotail, magnetosheath, bow shock, and foreshock; 3. far downwind from Earth in all the foregoing interaction regions; 4. in the solar wind approaching and following G-Z encounter; and 5. near the comet itself. The data have been only partially explored or studied in detail, although some of the locations of the spacecraft have provided measurements duplicated in no other database. In fact, processing of the pw data had not even advanced, until this report interval, beyond routine output unsuited to analysis of many of the enumerated regions. We have sought therefore to pursue our processing and analysis tasks in a way calculated to balance the scientific objectives between those obtainable from recent data acquisition in the solar wind and from older data subject to revisitation in great detail and/or with innovative processing to reveal hitherto inconspicuous or overlooked phenomenology.

*Activities*. The interval reported on here, from January 1990 to December 1991, has been one of continued processing and archiving of ICE plasma wave (pw) data and transition from analysis of ISEE 3 and ICE cometary data to ICE data taken along its cruise trajectory, where coronal mass ejections are the focus of attention. We have continued to examine with great interest the last year of ISEE 3's precomet phase, when it spent considerable time far downwind from Earth, recording conditions upstream, downstream, and across the very weak, distant flank bow shock. Among other motivations has been the apparent similarity of some shock and post shock structures to the signatures of the bow wave surrounding comet Giacobini-Zinner, whose ICE-phase data we have revisited.

While pursuing detailed, second-order scientific inquiries still pending from the late ISEE 3 recordings, we have also sought to position ourselves for study of CMEs by instituting a data processing format new to the ISEE 3/ICE pw detector. Processed detector output has always been summarized and archived in 24-hour segments, with all pw channels individually plotted and

stacked one above the next down in frequency, with each channel calibrated separately to keep all data patterns equally visible in the plots, regardless of gross differences in energy content at the various frequencies. Since CMEs, with their preceding and following solar wind plasmas, can take more than one day to pass by the spacecraft, a more condensed synoptic view of the pw data is required to identify, let alone assess, CME characteristics than has been afforded by the traditional routines. We addressed this requirement in a major new processing initiative in the past two years.

Besides our own ongoing and fresh investigations, we have cooperated, within our resources, with studies conducted extramurally by distant colleagues irrespective of the phase of the ISEE 3/ICE mission under scrutiny. The remainder of this report summarizes our processing activities, our investigations, both internal and cooperative, our scientific results, and our publication activity.

## DATA PROCESSING

Routine processing ICE PW data has been completed to the following dates:

*Backup of tapes for TRW.* Through October 1991.

*Hardcopy (paper), multichannel plots.* Through July 1990.

*Microfiche of hardcopy for archiving.* Through 1988.

*G-Z encounter tapes.* All data covering the Giacobini-Zinner (G-Z) encounter by ICE were copied onto magnetic tape and shipped to GSFC archives, along with notes and a tape log.

Special processing was conducted, consisting of: 1. plotting spectra and sections of high resolution data for TRW studies, and 2. copying processed tapes or mailing processed data electronically, in support of studies by German, Japanese, and American investigators.

Processing for TRW studies included two new initiatives, an update of existing programs to display data in polar plot format and show polarizations relative to both the sun line and the instantaneous magnetic field, and a new survey format to compress pw data into multiday and monthlong displays for synoptic views of orbital and solar cycle wave patterns.

The polar plots have been helpful in estimating the true frequencies and wavelengths of high resolution spectral peaks. Our new survey format for the pw records consists primarily of color plots of the multichannel data, incorporating frequency smoothing and arbitrary time-averaging. These "channel-based spectrograms" we'll call "cbs's" are being applied to two areas of interest: 1. A preliminary study of plasma wave signatures of

CMEs and solar wind structures in general, and 2. Investigation of the patterns of plasma wave occurrence in Earth's magnetosheath and foreshock, particularly in the far downwind region (pursued concurrently with a separate GI program).

The first cbs runs are in progress. Since the low data rate of recent ICE measurements makes it highly improbable that events can be detected without appreciable time-compression, or interpreted without experience with such time-compression during earlier years when data acquisition was more complete, we have begun by examining some known intervals already studied. Copies of two of these were included in the third quarterly report of 1991. In one, we showed a cbs of the most promising pw and em channels for a 33-hr CME interval studied by *Neugebauer* [*Science,,252,* 19 April 1991, p404], for which plasma and magnetometer records have already been published. An initial interplanetary (IP) shock was visible in pw and em panels, with more pw and em activity evident in a second post shock interval that followed. Signals from a Type III burst were obvious in the highest three channels and there was an abrupt suspension of pw and cutoff of em activity near the end of the second day's record, when an IP discontinuity passed ISEE 3. Interested readers are referred to the *Neugebauer* article for correlative data plots. Characterizing the patterns of pw enhancement in such events will initiate our approach to examining CMEs during the ISEE 3/ICE lifetime.

In this report we attach a copy of a cbs illustrating two aspects of the new format: first, the compression into one page, of a 27-day interval, corresponding to a solar rotation period, and second, an application of the technique to one of the long passes of ISEE through Earth's magnetosheath. At left in the figure the satellite began in the geotail, marked by relative quiet in the electromagnetic channels of the lower panel, then emerged, in about day 249 (1983), into the magnetosheath more than 150 $R_E$ downstream. The spacecraft proceeded both sunward and outward through the sheath's increasingly bright pw activity (upper panel) and after many intense (scarlet) crossings of the bow shock entered the foreshock in the solar wind on day 268. No such overall account of a long sample of Earth's plasma wave environment at this location has previously been developed, and there are several more, not shown here. These will be a guide to us in selecting the most promising subintervals for detailed study of the physics of the interaction region. We shall also survey active and inactive solar periods and CMEs with such 27d plots.

## SCIENTIFIC RESULTS

*Re-examination of pw measurements at the highest resolution.* Attempts to understand apparently impulsive pw signals in the shock and post shock environments of G-Z and the earth led to careful examination of the records at the highest sampling rates and review of the original instrument calibrations. We clarified the seeming unreproducibility of sequential spectra, concluding that hitherto undifferentiated modes are present sporadically in the data, particularly in Earth's bow shock. As this report is written, we are preparing to compute and examine polarization plots to help determine the effect, if any, of Doppler effects on the signals.

We are concluding tentatively that the ISEE 3/ICE pw detector in and behind the shock was picking up real wavemodes not previously noted and that these wavemodes may persist for tens or hundreds of Earth radii downstream, with only moderate damping in the magnetosheath plasma. The implications of this conclusion for the physics of the affected regions and for the design of future instruments and analysis of their data is under study.

*Magnetic profiles of weak shocks.* Examination of many weak, low Mach number crossings of the distant, downwind flank shock revealed repeated quasi-parallel ($Q_{\|}$) profiles with large magnetic waves behind the shock ramps. Previous experience with weak, subsolar shocks found typical profiles consisting of damped, standing whistler precursors in front of the ramps. A comparison between a few of our profiles and Q$\|$ simulations under study at the Univ. of California, San Diego, suggested strongly that the Alfvèn Mach number, rather than the magnetosonic Mach number, is the critical parameter in determining the structure of weak shocks, as described in a published paper listed below [*Greenstadt et al.*, 1990]. This was primarily a magnetic field study; the correlative plasma wave study is in preparation.

*Plasma wave feet of weak shocks.* Motivated by a need to follow up earlier studies of weak, quasi-perpendicular (Q$\perp$) subsolar shocks, we sought to confirm or delimit the presence of tenuous populations of reflected ions ahead of the many flank shock crossings at our disposal. We did this by inspecting them for pw feet in the ion acoustic range of frequencies, since such pw signals are sensitive indicators of counterstreaming ions. We extended the inspection to Q$\|$ shocks as well, since we expected to find ions escaping upstream from them, causing pw activity useful for comparison of signal levels.

We found that Q$\perp$ pw feet are common for our weak shocks, but variable in wave amplitude and spatial extent upstream from the ramps. Geometric analysis suggested that the direction of the interplanetary magnetic field (IMF) plays a key role in encouraging or discouraging the presence of pw feet in Q$\|$ cases, because of its effect on the upstream trajectories of nonlocally reflect-

ed ions. At some times distant ions are convected outside the shock toward the observation point; at other times even locally reflected ions are convected away from the observation point. This provides a reasonable explanation for the variability of pw foot profiles. We also found that the pw feet grow in extension from their shocks, forming pw foreshocks as the shock normal angle $\theta_{Bn}$ drops toward and into the $Q\|$ range below 45°, and that pw intensities are essentially the same at weak shocks as they are at strong shocks. These results are summarized below in the abstract of the paper, "Plasma Wave Profiles of Earth's Bow Shock at Low Mach Numbers: ISEE 3 Observations on the Far Flank" by Greenstadt, Coroniti, Moses, and Smith, awaiting publication as the present report is written.

*Coronal shocks.* Considerations of plasma theory and ISEE 3 observations of weak flank shock crossings led to the proposal that weak, i.e. low Mach number, fast shocks might be expected in the region intended to be traversed by the Solar Probe mission. Scaling and Doppler computations indicated that a plasma wave instrument would need to be prepared for detection of large amplitude signals at 100 kHz.

*Comet Giacobini-Zinner interaction.* Study of the pw data from the downwind passage by ICE through Giacobini-Zinner (G-Z) was renewed by inspection of spectra at the highest sampling rate of the pw instrument. The result was to resolve the previously averaged, relatively featureless or singly peaked, spectra into multipeaked spectra reminiscent of those being found in the distant crossings of Earth's weak, downwind bow shock (see earlier subsection). The absence of photoionization products among the ion populations in Earth's shock suggests that such a photoionic subpopulation may not necessarily be the explanation for the spectral characteristics of the G-Z signals. A report, submitted to J. Geophys. Res. is in the journal's review process at this time.

## COOPERATIVE EFFORTS

We furnished data and cooperated in the development of three studies, one in the solar wind, another in the magnetotail, and a third in the deep tail boundary layer. All joined pw to other measurements to describe interplanetary, substorm, and boundary events, respectively.

The substorm paper particularly demonstrated the advantage in sensitivity of ISEE 3's pw detectors for marking plasma transients in the magnetotail. Traveling compression regions were observed and attributed to plasmoids moving antisunward from the tail reconnection region with speeds determined from time delays between the near-Earth tail and local passage by ISEE 3. The

near-Earth launch of the plasmoids was estimated best from onset of 100 kHz AKR picked up by the pw instrument.

The boundary layer study, conducted by Tsutsui while at UCLA and completed on his return to Japan, showed that dispersion relations obtained from assumed Doppler shifting of pw spectra were consistent with theoretical ion acoustic dispersions for measured electron parameters and that ion temperatures were in a range from 1 to 4 times the electron temperatures. A published paper is listed below.

In the solar wind, two papers grew out of pw data sent to Dr. Wolfgang Droege and colleagues, dealing with cosmic ray transport in the interplanetary medium:

"Interplanetary Transport of Solar Cosmic Rays," by Achatz, Droege, Schlickeiser, and Wibberenz, published in the Proc. 22nd International Cosmic Ray Conference, Dublin, Ireland, Vol. 3, 240-243, 1991. (Also submitted to J. Geophys. Res., 1992)

"Hochfrequente Fluktuationen elektromagnetischer Felder im Sonnenwind und ihr Einfluss auf die Ausbreitung energetischer solarer Elektronen," by Droege, Achatz, Schlickeiser, and Wibberenz, presented to the 56th Physikertagung der Deutschen Physikalischen Gesellschaft, Berlin, Germany, March, 1992.

## PUBLICATIONS

Published papers generated by this program are listed below. Copies of abstracts of reports not yet printed follow the publication list.


Memorial review. Moses, S. and Charles Kennel, Plasma waves at collisionless shocks in space: the observations of Frederick L. Scarf, *Adv. Space Res. 11*, (9)3-(9)14, 1991.

Greenstadt, Moses, Coroniti, Tsurutani, Omidi, Quest, and Krauss-Varban, Weak, Quasiparallel Shocks: A Comparison between ISEE 3 Observations and Numerical Simulations, *Geophys. Res. Lett.*, *18*, 2301-2304, 1991.

Moses, S. L., F. V. Coroniti, E. W. Greenstadt, and B. T. Tsurutani, Wave Amplitudes in Shocks in the Solar Corona: Predictions for Solar Probe, *J. Geophys. Res.*, *96*, 21,397-21,401, 1991.

Tsutsui, M., R. J. Strangeway, B. T. Tsurutani, H. Matsumoto, J. L. Phillips, and M. Ashour-Abdalla, Wave mode identification of electrostatic noise observed with ISEE 3 in the deep tail boundary layer, *J. Geophys. Res.*, *96*, 14,065-14,073, 1991.


## PENDING, UNPUBLISHED REPORTS

Weak pw shock signatures. describing the observations of plasma

wave feet confirming the likely presence of reflected ions outside the magnetic ramps of the weak shocks of the distant flank of Earth's bow shock, has been accepted for publication in JGR. Camera-ready copy will be sent to publication shortly.

High resolution G-Z data. The paper "Observations of plasma waves in the Solar Wind Interaction Region of Comet Giacobini-Zinner at High-Time Resolution" whose results were discussed in the last quarterly and briefly earlier in this report, has been reviewed and revised and is awaiting acceptance

Magnetotail plasmoids. The paper "ISEE 3 plasmoid and TCR observations during an extended interval of substorm activity" by Slavin, Smith, Mazur, Baker, Iyemori, Singer, and Greenstadt has been submitted to J. Geophys. Res., refereed, revised, and accepted for publication.